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RESEARCH SYMPOSIUM

**APPLICATION OF MODEL-BASED SYSTEMS
ENGINEERING METHODS TO DEVELOPMENT
OF COMBAT SYSTEM ARCHITECTURES**

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by

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14. ABSTRACT

Navy acquisition activities frequently produce combat system architectures based on existing systems rather than on stakeholder requirements. This approach limits software component reuse, which, in turn, limits potential application to other platforms. The objective of this Capstone project was to develop a methodology for creating complex combat system architectures that emphasize the use of Software Product Lines (SPLs), requirements traceability, integrated supportability and Modeling and Simulation (M&S) early and throughout the approach. To address this objective, an integrated methodology that utilizes Model-based Systems Engineering (MBSE) to create open, supportable combat system architectures was developed. The methodology was evaluated by applying it to a naval surface combatant Anti-Air Warfare (AAW) mission area. Application of the methodology led to the following major findings (1) Proven systems engineering practices, languages and tools can be integrated with the MBSE approach for developing complex architectures; (2) Creation of domain-centered SPLs facilitates planned reuse and allows for assessment to candidate architectures; (3) Requirements traceability can be achieved by using a combination of modeling languages and tools; (4) M&S application can extend beyond operational scenarios to address lifecycle cost and (5) Engineers and logisticians can effectively use MBSE to integrate supportability into design. Overall, this project demonstrated the benefits of an MBSE approach tailored to developing affordable and supportable combat system architectures that meet mission requirements

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Proceedings of the Annual Acquisition Research Program

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Application of Model-based Systems Engineering Methods to Development of Combat System Architectures

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Abstract

Navy acquisition activities frequently produce combat system architectures based on existing systems rather than on stakeholder requirements. This approach limits software component reuse, which, in turn, limits potential application to other platforms. The objective of this Capstone project was to develop a methodology for creating complex combat system architectures that emphasize the use of Software Product Lines (SPLs), requirements traceability, integrated supportability and Modeling and Simulation (M&S) early and throughout the approach. To address this objective, an integrated methodology that utilizes Model-based Systems Engineering (MBSE) to create open, supportable combat system architectures was developed. The methodology was evaluated by applying it to a naval surface combatant Anti-Air Warfare (AAW) mission area. Application of the methodology led to the following major findings: (1) Proven systems engineering practices, languages and tools can be integrated with the MBSE approach for developing complex architectures; (2) Creation of domain-centered SPLs facilitates planned reuse and allows for assessment to candidate architectures; (3) Requirements traceability can be achieved by using a combination of modeling languages and tools; (4) M&S application can extend beyond operational scenarios to address lifecycle cost, and (5) Engineers and logisticians can effectively use MBSE to integrate supportability into design. Overall, this project demonstrated the benefits of an MBSE approach tailored to developing affordable and supportable combat system architectures that meet mission requirements.

Overview

This paper is a description of the Master of Science in Systems Engineering Capstone project completed by the students of Cohort Six from Naval Surface Weapons Center, Port Hueneme, CA. They were assigned this problem because Navy acquisition activities frequently produce combat system architectures based on existing systems rather than on stakeholder requirements. This approach limits software component reuse, which, in turn, limits potential application to other platforms. The development of systems tends to be by platform rather than by application or warfare area. A second system development issue is that *Department of Defense Instruction* (*DoDI*) *5000.02* (2008) prescribes the early integration of supportability requirements; however, current methods or processes do not do so. Methodologies currently in

use—such as the Acquisition, Technology, and Logistics framework—may identify supportability as a requirement but tend not to maintain it as a priority throughout the development process.

In response to these issues, an integrated methodology that utilizes MBSE and the Agile process was defined to create open and supportable system architectures. This methodology incorporates a common modeling language, utilizes domain analysis to support Software Product Line (SPL) reuse, maintains traceability of requirements and architecture functionality, and integrates supportability, sustainment and lifecycle cost considerations. Also described in this project is a system engineering process that outlines requirements generation analysis, functional analysis and allocation, architecture definition, and Verification and Validation (V&V).

The methodology was evaluated by applying it to an Anti-Air Warfare (AAW) mission thread—in particular, Anti-Ship Missile Defense (ASMD). The AAW implementation included the development of a systems architecture and design artifacts, including Department of Defense Architecture Framework (DoDAF) views. The project demonstrated the benefits of an MBSE approach tailored to developing architectures that support Open Architecture (OA), SPL, and integrating supportability early in the system development process. Technical conclusions resulting from the research, development and application of the methodology are summarized in the following paragraphs.

Problem Statement and Capstone Objective

Recognizing that current DoD processes for developing combat system architectures are heavily influenced by legacy processes and systems—which inhibit the incorporation of supportability requirements up-front in design—project leaders assigned the students to meet the DoD objective of acquiring and fielding interoperable, supportable system architectures that utilized the Open Architecture (OA) paradigm. They were further tasked to address the use of Software Product Lines (SPLs) and capture the results in a form that was compliant with the DoD Architecture Framework (DoDAF). They were specifically told to develop a MBSE approach. In addition, they were to integrate supportability issues, requirements traceability and identify a structure which supports combat system software reuse.

Project Organization

Figure 1 shows the various organizational structures the students adopted as they progressed through the project. At first there was a reluctance to change, but eventually they learned that they had to adapt the organization to the task. Once that lesson was learned, the students became proficient in developing their work products.
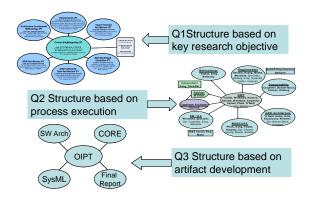
Figure 1. IPT Structure Evolving with Capstone Project Need

Two other lessons learned were that small teams were more efficient and that the project needs a chief architect.

Methodology Overview

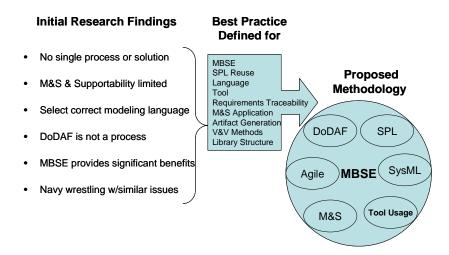The result of the literature searches into each element of the problem set is summarized in Figure 2.

Figure 2. Overview of the Model Development

The initial research findings are significant in that the students came to understand that development of complex systems requires a through understanding of processes and tools available. Figure 3 illustrates how the students integrated the literature with practice.
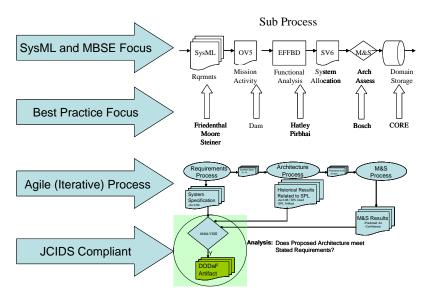
Figure 3. The Big Picture

Two of the takeaways from Figure 3 are these: 1) to deal with complex problems, one requires multiple frames of reference, and 2) integration of methods is needed to provide a more complete description of the potential solution. The following paragraphs provide more detail about the approach the students developed.

Methodology Top-tier Process

Figure 4 is the representation of how the students viewed the process of going from a specification to architecture.
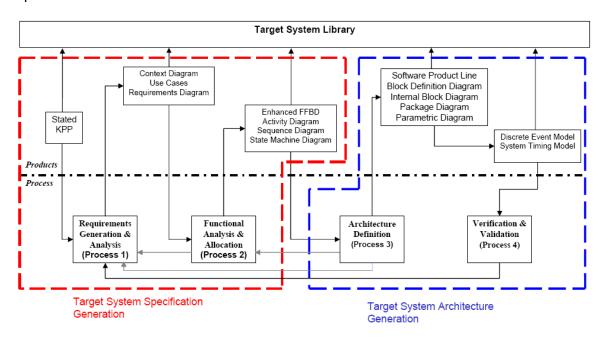
Figure 4. The Overall Methodology

They developed four main processes as shown in the figure above: (1) requirements generation and analysis, (2) functional analysis and allocation, (3) architecture definition, and (4) verification and validation. They verified these processes by developing an AAW Mission Architecture. The following paragraphs describe the four sub-processes.

(1) Requirements Generation and Analysis Process

Figure 5 provides the detail of the requirements generation and analysis step and how it interfaces with the other three steps in the methodology. Figure 6 shows the outcome of the requirements step.

Requirements lessons learned can be summed up as follows:

- It was necessary to expand the use of modeling because of the insights it provided in requirements decomposition and allocation. M&S can result in improved decomposition and allocation.

- It was important to understand the relationship between requirements artifacts for traceability at the tier level and across artifact boundaries.

- It was essential to keep the requirements tool set database current for both traceability and verification of allocation.

- Process execution improved over time; i.e., the teams became more effective with experience.

- The process resulted in valid artifacts that support Capstone objectives.

- The tools, skill sets, and processes are not in place to lead requirements development on large, complex systems.
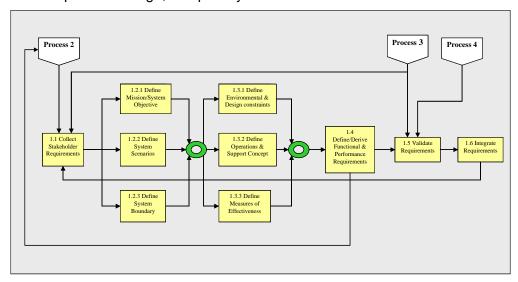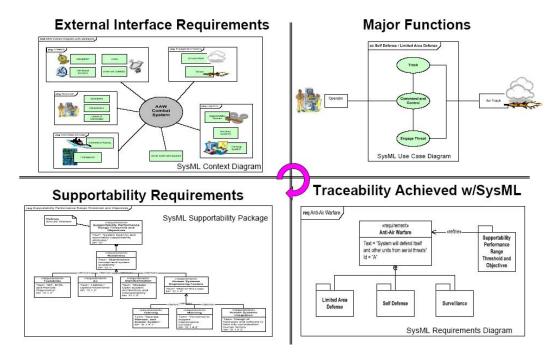
Figure 5. The Requirements Generation Process

External Interface Requirements

SysML Context Diagram

Major Functions

SysML Use Case Diagram

Supportability Requirements

SysML Supportability Package

Traceability Achieved w/SysML

SysML Requirements Diagram

Figure 6. Requirements Results/Products

(2) Functional Analysis and Allocation Process

The approach to functional analysis was straightforward and is shown in Figure 7. Some of the key lessons learned were to plan tool usage. The process is iterative, and the data is developed in a drill-down manner. A second point was that to ensure that the result is correct, a subject-matter expert (SME) is important and should be readily available; otherwise, there is a tendency for engineers to map based on experience. The level of input is only as good as the SME's knowledge. It should be noted that technical, language, method, and tool SMEs are different and that a blend of talent is required.
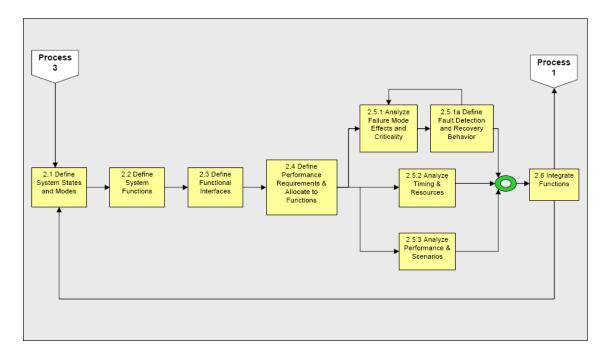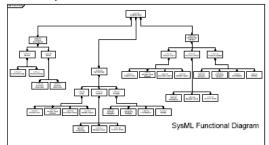
Figure 7. Functional Analysis Process Diagram
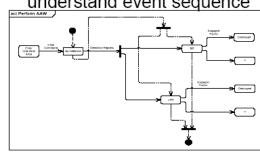
Figure 8 shows some of the key artifacts developed during this part of the process. The artifacts provided powerful depictions for communicating and for analysis in design and development.

In the execution of the process, the Hatley-Pirbhai method was integrated with the SysML language to provide a sound SE approach within the MBSE format. The outcome of this approach is a requirements model, as shown on the left side of Figure 9. The architecture process diagram illustrates how the students built the right side of the model.
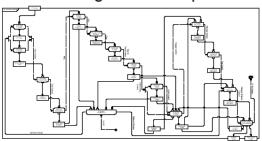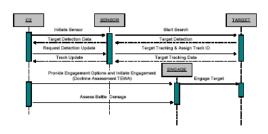
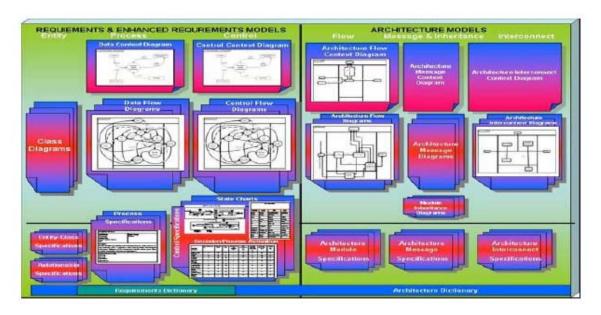**Figure 8. Functional Analysis Results/Products**

Figure 9. The Hatley-Pirbhai Models

(3) Architecture Definition Process

The development of the architecture followed the process shown in Figure 10. In developing the architecture from the previous step, the students encountered some interesting issues. First, there was a lack of core knowledge in the architecture development process. Use

of the Hatley-Pirbhai paradigm provided an approach that overcame the inexperience issue. Figure 11 is the Hatley-Pirbhai architecture template. This template is reusable at every level of analysis and allows for a more formal approach than natural language descriptions.
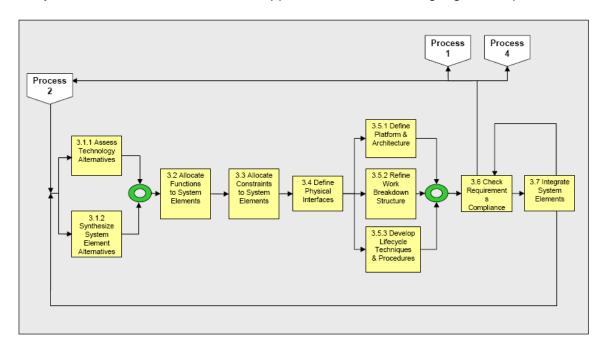

Figure 10. Architecture Process Diagram

Figure 11. Hatley-Pirbhai Architecture Template

There was also an issue with software architecture quality attributes not being fully defined or measurable. The student solution was the use of an objective hierarchy to assess architecture, as shown in Figure 12. One of the subtle realizations by the students was the applicability of Six Sigma techniques to all the steps discussed so far.

The students initially had a problem with a lack of common task and function descriptions. This was caused by different teams working on different parts of the problem using different tools. This issue was resolved as the students reorganized and reduced the size of the team working on this area.
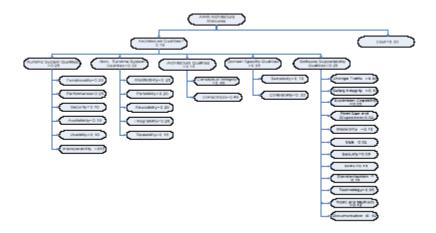
Figure 12. SW Architecture Objective Hierarchy

This reorganization helped with developing the software architecture shown on the left side of Figure 13. Figure 13 shows the relationship of the software architecture to the production plan (much simplified in this diagram) to the product line library on the right.
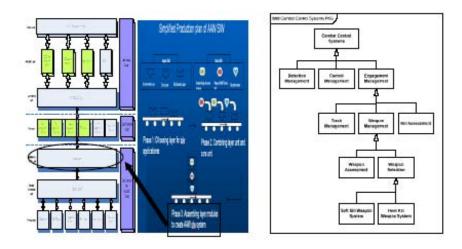

Figure 13. Project Software Architecture and SPL Library Framework

(4) Verification and Validation Process

As shown in Figure 14, modeling and simulation was used to identify both feasibility and configuration performance differences, as well as to verify requirements. The parallel analysis efforts for functional analysis and architecture development required adaptable models that could be updated as Systems Engineering artifacts were created. The students initially had problems with trying to put too much detail into the model rather than focusing on process execution. As they gained experience, they were able to use a block-oriented simulation language to develop model variations very quickly.
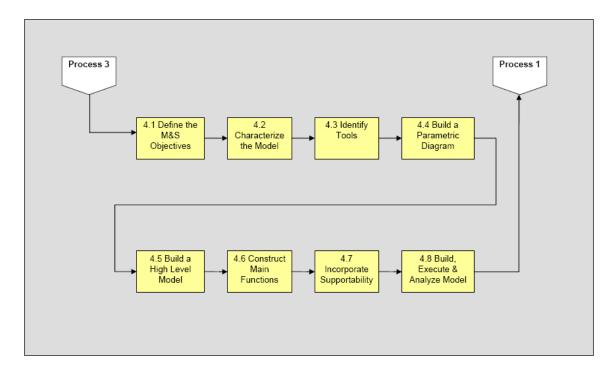
Figure 14. M&S Process Diagram

Overall, M&S provided valuable insight into architecture design, requirements decomposition, and related performance issues.

Capstone Conclusions and Recommendations

The students made the following recommendations. First, provide logisticians with the background to participate early in the acquisition cycle. In this study, logisticians demonstrated the required skills to work in systems concept and development. Second, establish domain-specific components and quality attributes. Identify a QA weighting system to balance sustainment and performance by domain. Third, develop SPL library criteria and characteristics. Define data tags required to assess SPL reusability. Fourth, continue the research effort to a V&V methodology. Execution of the methodology to develop S/W, H/W and Interface Components will result in additional findings/lessons learned. Finally, leverage the methodology to estimate lifecycle cost and RAM through M&S, and use artifacts to support early LCCE and RAM KPP reporting requirements.

Overall Project Summary

Proven systems engineering practices, languages and tools can be integrated with the MBSE approach for developing complex architectures. Through decomposition of the objectives and associated research, the students were able to identify many solutions and methodologies available to support a top-down or bottom-up approach. Based on tenets from multiple authors, the student teams developed a new end-to-end methodology for system design—to include key aspects in requirements generation, architecture development, and modeling and simulation.

Requirements traceability can be achieved by using a combination of modeling languages and tools. Traceability is critical on large, complex systems due to the sheer volume

of technical data and the likelihood of human error when trying to conduct V&V manually using engineering artifacts. Students achieved requirements generation and traceability using the Systems Modeling Language (SysML) as the modeling language and CORE as the architecture tool. They reduced manual V&V errors, given that SysML contains methods based on the allocation relationship depicted in the artifacts for verifying traceability. They used sample test criteria and events to successfully verify that CORE could be used to assess demonstration of requirements.

M&S can provide significant value in conducting tradeoffs during design. However, the majority of M&S is focused on verifying operational parameters within scenarios vice optimizing system design. Students applied M&S using a top-down approach to verify system operational behavior and to validate initial operational requirements. They used the software tool Extend to perform the simulation of a raid scenario. Through multiple variations of models and simulations, it was found that there could be anomalies or elements that need adjustment in the architecture. The unexpected results from the raw data led to more extensive research of the initial inputs, which led to additional simulation runs. Defining objectives, processes and model development were all key milestones in building the Extend model.

Engineers and logisticians can effectively use MBSE to integrate supportability into system design. The Navy advocates the integration of supportability early in the concept development and design phases, but very little training or guidance is provided on how to effectively do this. Many logisticians are not equipped with the knowledge or experience to adequately support initial system concept and architecture development. Similarly, many design engineers lack the training and experience of considering supportability during concept exploration, design and development. On this project, engineers and logisticians collaborated to meet the expressed objective of integrating supportability into design as depicted in the resulting artifacts. Supportability was considered during requirements generation, functional analysis and architecture composition. The integration of supportability early in design provided the maintenance concept and planning phases with a solid foundation for conducting tradeoff decisions between operational enhancements and lifecycle sustainment considerations.

List of References

MSSE/MSSEM Cohort 6. (2009, March). Application of model based systems engineering methods to development of combat system architectures (NPS-SE-09-002). Monterey, CA: Naval Postgraduate School.

USD (AT&L). (2008, December 8). *Operation of the defense acquisition system* (DoD Instruction 5000.02). Washington, DC: Author.

2003 - 2009 Sponsored Research Topics

Acquisition Management

- Acquiring Combat Capability via Public-Private Partnerships (PPPs)
- BCA: Contractor vs. Organic Growth
- Defense Industry Consolidation
- EU-US Defense Industrial Relationships
- Knowledge Value Added (KVA) + Real Options (RO) Applied to Shipyard Planning Processes
- Managing Services Supply Chain
- MOSA Contracting Implications
- Portfolio Optimization via KVA + RO
- Private Military Sector
- Software Requirements for OA
- Spiral Development
- Strategy for Defense Acquisition Research
- The Software, Hardware Asset Reuse Enterprise (SHARE) repository

Contract Management

- Commodity Sourcing Strategies
- Contracting Government Procurement Functions
- Contractors in 21st Century Combat Zone
- Joint Contingency Contracting
- Model for Optimizing Contingency Contracting Planning and Execution
- Navy Contract Writing Guide
- Past Performance in Source Selection
- Strategic Contingency Contracting
- Transforming DoD Contract Closeout
- USAF Energy Savings Performance Contracts
- USAF IT Commodity Council
- USMC Contingency Contracting

Financial Management

- Acquisitions via leasing: MPS case
- Budget Scoring
- Budgeting for Capabilities-based Planning
- Capital Budgeting for DoD

- Energy Saving Contracts/DoD Mobile Assets
- Financing DoD Budget via PPPs
- Lessons from Private Sector Capital Budgeting for DoD Acquisition Budgeting Reform
- PPPs and Government Financing
- ROI of Information Warfare Systems
- Special Termination Liability in MDAPs
- Strategic Sourcing
- Transaction Cost Economics (TCE) to Improve Cost Estimates

Human Resources

- Indefinite Reenlistment
- Individual Augmentation
- Learning Management Systems
- Moral Conduct Waivers and First-tem Attrition
- Retention
- The Navy's Selective Reenlistment Bonus (SRB) Management System
- Tuition Assistance

Logistics Management

- Analysis of LAV Depot Maintenance
- Army LOG MOD
- ASDS Product Support Analysis
- Cold-chain Logistics
- Contractors Supporting Military Operations
- Diffusion/Variability on Vendor Performance Evaluation
- Evolutionary Acquisition
- Lean Six Sigma to Reduce Costs and Improve Readiness
- Naval Aviation Maintenance and Process Improvement (2)
- Optimizing CIWS Lifecycle Support (LCS)
- Outsourcing the Pearl Harbor MK-48 Intermediate Maintenance Activity
- Pallet Management System
- PBL (4)
- Privatization-NOSL/NAWCI
- RFID (6)
- Risk Analysis for Performance-based Logistics
- R-TOC Aegis Microwave Power Tubes

- Sense-and-Respond Logistics Network
- Strategic Sourcing

Program Management

- Building Collaborative Capacity
- Business Process Reengineering (BPR) for LCS Mission Module Acquisition
- Collaborative IT Tools Leveraging Competence
- Contractor vs. Organic Support
- Knowledge, Responsibilities and Decision Rights in MDAPs
- KVA Applied to Aegis and SSDS
- Managing the Service Supply Chain
- Measuring Uncertainty in Earned Value
- Organizational Modeling and Simulation
- Public-Private Partnership
- Terminating Your Own Program
- Utilizing Collaborative and Three-dimensional Imaging Technology

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Application of Model-Based Systems Engineering

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Agenda

- **Capstone Objective**
- **Overview of Q1 and Q2**
  - Team Organization
  - Execution & Scope
  - Research
  - Methodology
- **Results & Products**
  - Requirements
  - Functional Analysis
  - Architecture
  - Modeling and Simulation
  - *CORE*
- **Capstone Conclusions**

Capstone Objective
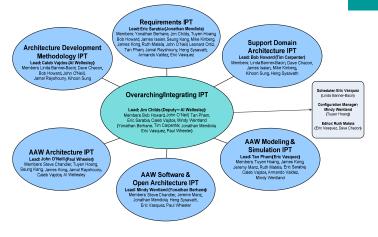
- **The Objective of this Project was to Develop a System Engineering (SE) Methodology for Creating Complex, Supportable System Architectures that:**
  - Utilize a Model Based Systems Engineering (MBSE) approach
  - Integrate Requirements Traceability
  - Implement Open Architecture (OA) and SPLs
  - Identify a structure which supports Combat System Software Reuse
  - Support early Integration of Supportability Requirements
  - Integrate DoDAF Artifacts with the Acquisition Requirements Process

Team Organization
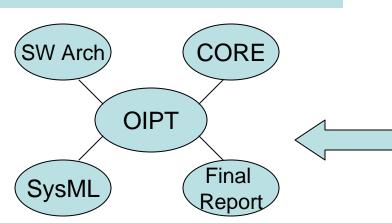
IPT Structure Evolved with CAPSTONE Need

Q1 Structure based on key research objective

Q2 Structure based on process execution

Q3 Structure based on artifact development

Primary Research Topics

Research Areas	Research Artifacts Quantity
Open Architecture	14
Service Oriented Architecture	2
DoD Architecture Framework	8
Domain Analysis	6
Software Product Lines	8
Model Based Systems Engineering	23
Systems Engineering "VEE"	3
Software Reuse	6
Process System Architecture & Requirements Engineering	3
Concept of Operations	1
Software Architecture Types	7
Modeling & Simulation	3
Systems Modeling Language	13
ExtendSim Tools & Discrete Event Modeling	2
CORE	4
Reliability Theory	3
Supportability	7
Anti-Air Warfare (P_{RA}, etc.)	10
Total = 123	

Research focused on tools, methodologies, languages which could be applied to meet capstone objectives

Crucial areas of project were researched more extensively (OA, MBSE, SysML, and AAW)
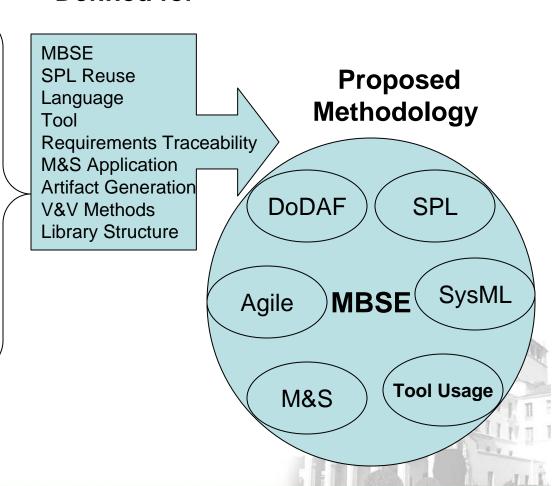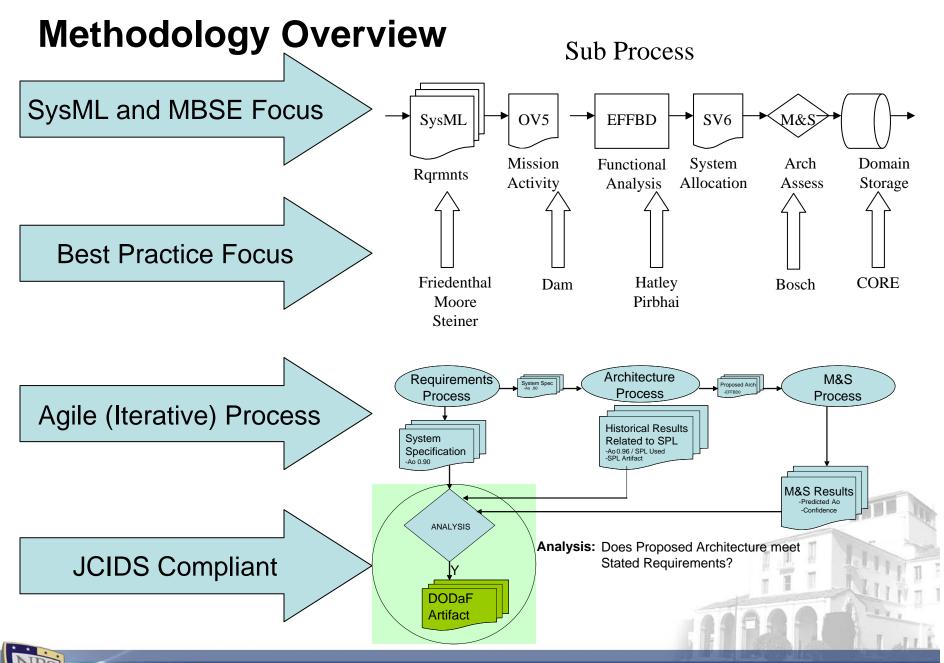
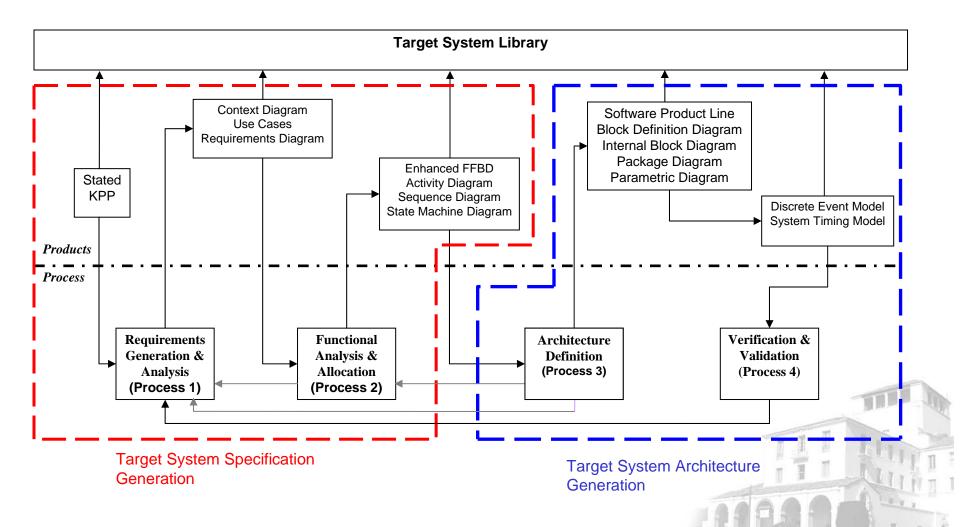# Research Application Methodology

Initial Research Findings

- No single process or solution

- M&S & Supportability limited

- Select correct modeling language

- DoDAF is not a process

- MBSE provides significant benefits

- Navy wrestling w/similar issues

Best Practice Defined for

MBSE
SPL Reuse
Language
Tool
Requirements Traceability
M&S Application
Artifact Generation
V&V Methods
Library Structure

Proposed Methodology

DoDAF   SPL

Agile   **MBSE**   SysML

M&S   Tool Usage

Methodology Overview

Sub Process

| SysML and MBSE Focus | ➤ | SysML | → | OV5 | → | EFFBD | → | SV6 | → | M&S | → | Domain Storage |

SysML — Rqrmnts
OV5 — Mission Activity
EFFBD — Functional Analysis
SV6 — System Allocation
M&S — Arch Assess
Domain Storage

Best Practice Focus ➤

Friedenthal Moore Steiner
Dam
Hatley Pirbhai
Bosch
CORE

Agile (Iterative) Process ➤

Requirements Process → System Spec -Ao .90 → Architecture Process → Proposed Arch -EFFBD0 → M&S Process

System Specification -Ao 0.90

Historical Results Related to SPL -Ao 0.96 / SPL Used -SPL Artifact

M&S Results -Predicted Ao -Confidence

JCIDS Compliant ➤

ANALYSIS

Y

DODaF Artifact

Analysis: Does Proposed Architecture meet Stated Requirements?

Methodology Top Tier Process

Target System Library

Context Diagram
Use Cases
Requirements Diagram

Software Product Line
Block Definition Diagram
Internal Block Diagram
Package Diagram
Parametric Diagram

Stated
KPP

Enhanced FFBD
Activity Diagram
Sequence Diagram
State Machine Diagram

Discrete Event Model
System Timing Model

Products

Process

**Requirements
Generation &
Analysis
(Process 1)**

**Functional
Analysis &
Allocation
(Process 2)**

**Architecture
Definition
(Process 3)**

**Verification &
Validation
(Process 4)**

Target System Specification
Generation

Target System Architecture
Generation

Approach to Verify Methodology

- Use Methodology to Develop an AAW Mission Architecture

- Meet the following MOEs:
  - Self Defense
  - Limited Area Defense
  - Surveillance

Requirements Issues and Resolutions

- **SysML Tool Availability**
  - **No software license for proven tools**
  - **No formal training available for proven tools**

Independent Research →
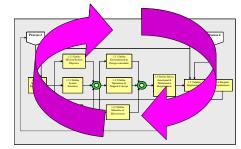
On-Line User Manuals
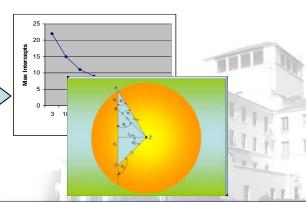
- **Baseline for Requirements**
  - **Schedule required, parallel development**

Interaction →
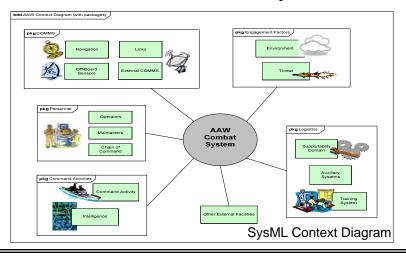
  - **Insufficient information to derive many of requirements needed for Parametric**

Target Track Geometry, Max # Intercepts @ CPA →
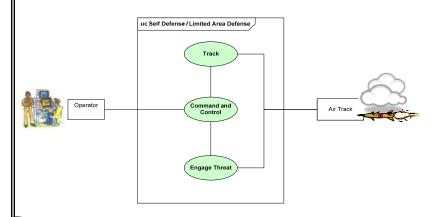
Requirements Results / Products

External Interface Requirements
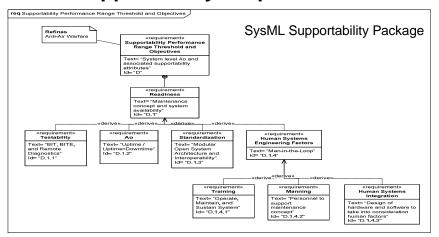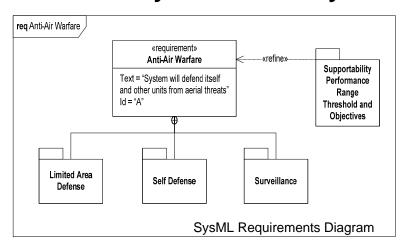
SysML Context Diagram

Major Functions

SysML Use Case Diagram

Supportability Requirements

SysML Supportability Package

Traceability Achieved w/SysML

SysML Requirements Diagram

Requirements Summary

- Process Execution

  - Improved over time
  - Teams became more effective with experience
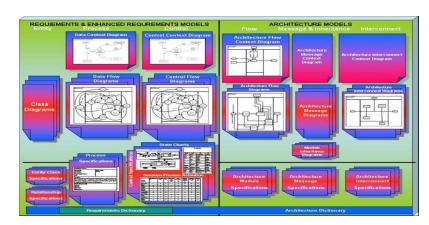
- Issues and Resolutions

  - Tools, KSAs and processes are not in place to lead requirements development on large complex systems
    - This Issue can be overcome to support PHD technical oversight and strategic objectives

- Artifacts

  - The process resulted in valid artifacts which support Capstone objectives

- Lessons Learned

  - Expand M&S Usage
    - Requirements Decomposition
    - Requirements Allocation
  - Understand Artifact Relationship
  - Maintain Tool
    - Traceability Establishment
    - Verification of Allocation

Defense Acquisition in Transition
6TH ANNUAL ACQUISITION RESEARCH SYMPOSIUM

May 12-14, 2009
Monterey, CA

NPS
PRAESTANTIA PER SCIENTIAM
1909

Functional Analysis Issues and Resolutions

- **Systems Engineering process to optimize allocation of functions**
  - **Deriving Software Requirements**
  - **Tendency to map based on experience**
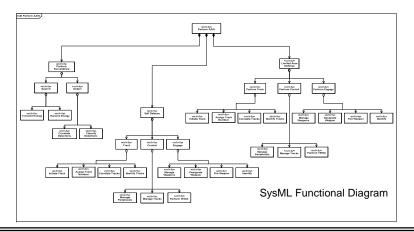
- **Common Domain and Functional Descriptions**

NTAs & UNTL
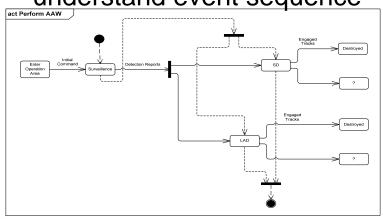
Functional Analysis Results / Products
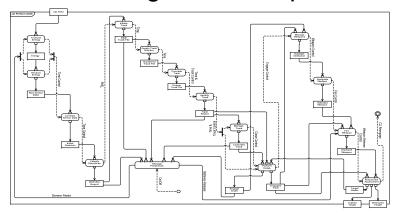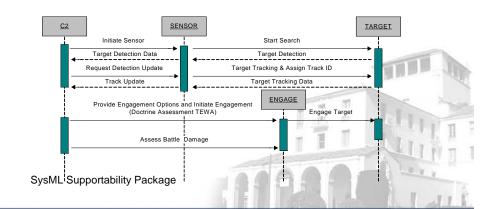
SysML traceability from requirements to functions

SysML Functional Diagram

Activity diagram used to understand event sequence

EEFBD provided control and timing relationships

Sequence diagram provides graphical representation

SysML Supportability Package
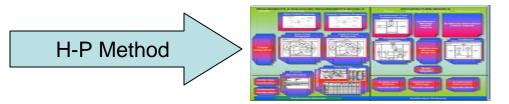
Functional Analysis Summary

- Process Execution
  - Hatley Pirbhai method was integrated with SysML language to provide a sound SE approach with a MBSE format

- Issues and Resolutions
  - Artifact development challenged by lack of inherent tools to develop, update and apply M&S to optimize design and verify traceability
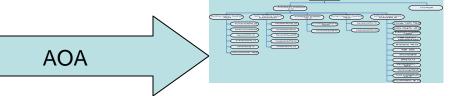
- Artifacts
  - Provide powerful depictions for communicating and analysis for design and development

- Lessons Learned
  - Process is an iterative loop in learning a flexible tool set
  - Ensure SME Availability

Architecture Issues and Resolutions
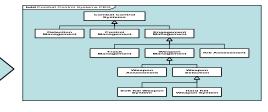
- Lack of Core Knowledge in Architecture Development Process

  H-P Method →

- Software Architecture Quality Attributes not fully defined or measurable

  AOA →

- Lack of DoD Common SPL Library

  Dewey Decimal System for Software →

- Lack of Common Task & Function Description

  Universal Task Listings →

Defense Acquisition in Transition
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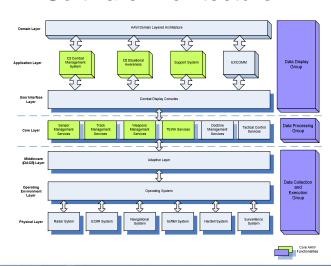# Architecture Results / Products

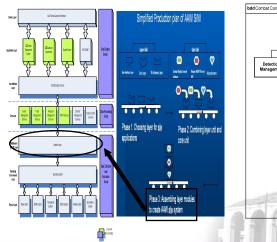## AAW System Specifications

Objective Hierarchy to Assess Arch

Software Architecture

AAW SPL Library Framework

Architecture Summary

- ## Process Execution
  - SysML
  - Hatley-Pirbhai / Bosch processes provided for:
    - allocating and optimizing functions to architecture

- ## Issues and Resolutions

  - Lack of Navy structure will continue to create "stand-alone" solutions

- ## Artifacts
  - Hatley-Pirbhai System Specifications (Limited)
  - AAW Software Architecture framework
  - Software Product Line (SPL) framework

- ## Lessons Learned
  - Solutions have been proposed by various leads within Navy (C4I/CS/HM&E) on OA and SPL
    - **Not Domain Based; Software Reuse still in future**
    - **Need M&S base to strategize early**

M&S Issues and Resolutions

- **NMCI Limitations**
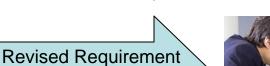 - VPN Connection to NPS Virtual Lab
  - License Issue

- **Extend Training**
  - Lack of Experience with Extend

- **Unrealistic Input Parameters**

Non-NMCI

DEMO Version

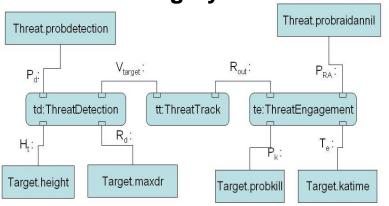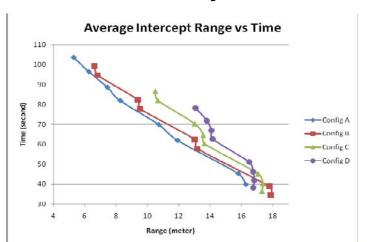User's Guide Tutorials

Revised Requirement with Stakeholder

M&S Results / Products
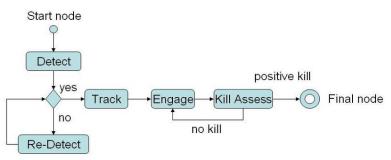
Requirements Traceability Using SysML

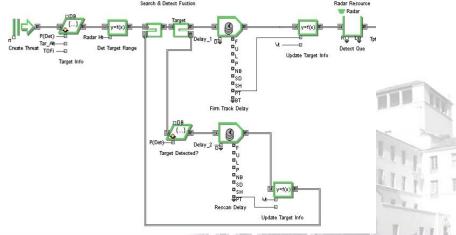SysML Parametric Diagram

Model Expansion Supported by Functional Architecture

High Level Model

Data Analysis

Model Derived from Architecture

Search & Detect Sub-Function

M&S Summary

- **Process Execution**
  - M&S was used to identify feasibility, configuration performance differences, and verify Requirements

- **Issues and resolution**
  - Parallel efforts required adaptable models that could be updated as Systems Engineering artifacts are created

- **Artifacts**
  - Physical modeling and P_{RA} simulation used to verify optimal configuration

- **Lessons Learned**
  - M&S provides valuable insight into architecture design, requirements decomposition, and other areas which are outside the traditional ISEA use

Capstone Conclusions
Major Findings

- **MBSE was Successful in Communicating Requirements and Information across Disciplines**

- **Best Process Integrates "best practices" from Language, Tools, and Processes**

- **Integration of Logisticians & Engineers improved Product Quality and inclusion of Supportability in Design**

- **Tools for Verification and Validation of Engineering Artifacts**

- **M&S Application extends beyond Operation Scenarios**

Capstone Conclusions Recommendations

- Develop Logisticians to support early acquisition
    - Logisticians demonstrated KSAs to work in SE Concept and Development
- Establish Domain-Specific Components/Quality Attributes
    - Identify QA Weighting System to Balance Sustainment and Performance by Domain
- Develop SPL Library Criteria and Characteristics
    - Define Data Tags required to assess SPL Reusability
- Continue Effort to V&V Methodology
    - Continuing System Decomposition based on Methodology
    - Execution of Methodology to Develop S/W, H/W and Interface Components will result in Additional Findings/Lessons Learned
- Leverage Methodology to Estimate Life Cycle Cost and RAM through M&S
    - Use Artifacts to Support Early LCCE and RAM KPP reporting Requirements

MSSE/MSSEM Program Conclusions

- Value added by having Engineers and Logisticians combined
  - Learned to "understand the languages"
  - Exposure to process increases ability to support
- Program directly contributes to PHD Strategic Goals
  - Provides KSAs to work "early acquisition"
  - Improves understanding of Systems Engineering process to sustain oversight
  - Increases Product Support Integrator (PSI) capability by increasing knowledge across sub-elements (Engineering, Logistics, T&E, Acquisition)
- Follow on Planning needed to minimize "Fire and Forget"